Quarkonia production in PHENIX/RHIC in 200 GeV p-p collisions

Denis Jouan
Institut de physique nucléaire, IN2P3/CNRS et Université Paris Sud XI, Orsay, France

Quarkonia production is a favoured tool both for studying production mechanisms and hot matter properties. An overview of the quarkonia production measured in pp collisions at $\sqrt{s} = 200GeV$ is presented. J/ψ ψ' χ_c and Υ are observed in dilepton measurements taken in 2006 with improved statistics.

Quarkonia are well know particles and usual elements in the landscape of high energy physics. But for about 15 years, their production have been challenging the model predictions. The color singlet model (CSM) failed to predict the cross section at TEVATRON [1], the color octet model (COM) seemed to solve the question, but failed on the polarization side[2]. Production in Nucleus-Nucleus (A+A) collisions also displayed unexpected features with a similar J/ψ suppression at SPS and RHIC energies. At the moment there is then no definite interpretation of the quarkonia production in p+p , p+A and A+A , but the extension of the measurements and of their precision in a wide energy domain is increasingly constraining the models. The advent of detectors like PHENIX, measuring many quarkonia on a wide kinematical range and with a variety of beams, joining separated areas of research , could allow to reach new observables, as the first tentative measurement of J/ψ production asymmetry with transversely polarized proton beams suggests.

This talk will concentrate on p+p production. d+Au and Au+Au are adressed in [3]. The PHENIX collaboration at RHIC collected data in p+p collisions at $\sqrt{s}$=200 GeV, allowing measurement of quarkonia states with a rapidity coverage of $|\eta| < 0.35$ (electrons pairs) and $1.2 < |\eta| < 2.4$ (muons pairs). Results are extracted from the 2006 run, with three time more luminosity than the 2005 [4] run.

When measuring pairs, there is a contribution of pairs coming from random combinations. This contribution is estimated from same sign pairs spectra or from mixed events. The remaining mass spectrum contains correlated pairs from $b\bar{b}$ and $c\bar{c}$ semi leptonic decays, and pairs from Drell Yan process and from resonances decays. These distributions are simulated, using PYTHIA generator and the simulation of the detector, and used in a fit.

In this new results, the Υ production is extracted separately from the continuum. The 1S, 2S and 3S states of the Υ are extracted together, and presented as a function of rapidity in Figure 1. The shape of this rapidity distribution is consistent with the prediction of the Color Evaporation Model [5]. A calculation in the Color Singlet NLO approximation [6] reproduces also very well the shape. This agreement is improved in this new extraction. The values of the Υ cross section are $BR * d\sigma/dy = 28.2 \pm 9.4(stat) \pm 4.8(syst)pb$ $(-2.2 < y < -1.2)$ and $BR * d\sigma/dy = 31.1 \pm 8.7(stat) \pm 6.2(syst)pb$ $(1.2 < y < 2.2)$.

Charmonia have a higher production rate, and also the same interesting properties than Υ :

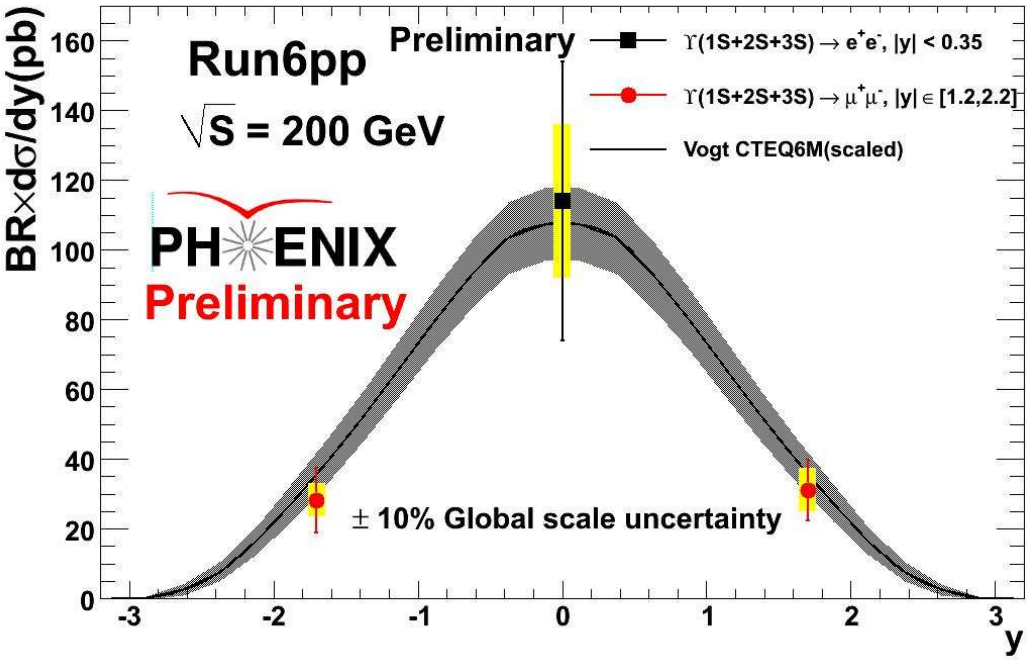

Figure 1: Rapidity distribution of the Υ resonances.

rare production, weak coupling with light mesons, a variety of states and binding energies, they can also be treated in the non relativistic approximation, which makes them attractive probes for studies of production or destruction (QGP melting) mechanisms. One complication arises from the side feeding from quarkonia higher states or from higher masses particles, which should imply to consider all these productions simultaneously. For instance an important fraction of the J/ψ comes from decays of χ_c , ψ' , and bottom quarks, and the J/ψ suppression pattern measured at SPS and RHIC could be due essentially to the melting of χ_c and ψ' states [7].

The Figure 2 displays the first p_T distribution of an excited charmonium state measured at RHIC. The ratio between ψ' and J/ψ agrees with that from other experiments [8,9]. The overall preliminary J/ψ feed down fraction from ψ' is $8.6 \pm 2.4\%$. This value is very consistent with the one deduced from p-A data around SPS energies 8.1 ± 0.3 % [10].

Feed-down fraction from χ_c is studied by looking at dielectron pairs in the J/ψ peak in coincidence with a photon in the electromagnetic calorimeter. Contribution of χ_{c1} and χ_{c2} lead to a gaussian contribution in the spectrum which must be separated from an underlying continuous component.

Preliminary studies at central rapidity led to an upper limit of 42 % (at 90% C.L.) for the fraction of inclusive J/ψ production originating from χ_c decay. This value is consistent with measurement from other experiments, mostly at lower energy, displayed in Figure 3, and with a recent selected average [10] leading to 25 ± 5 % . Mean value and uncertainties are on the way, together with estimates at forward rapidity.

As observed in CDF results previously mentionned, The J/ψ rapidity and transverse momentum distributions [11] have been found consistent with predictions from Color Octet Model [12]. They can be reproduced also by the Color Singlet Model, either through S-channel cut [13] alternative approach, either when additional contributions are taken into account: NLO contributions and charm initiated processes [14] or NNLO [15].

Such good agreement has been proved in the past [2] not to imply the agreement of the predictions regarding the polarization. In the helicity frame, the polarization characterizes the

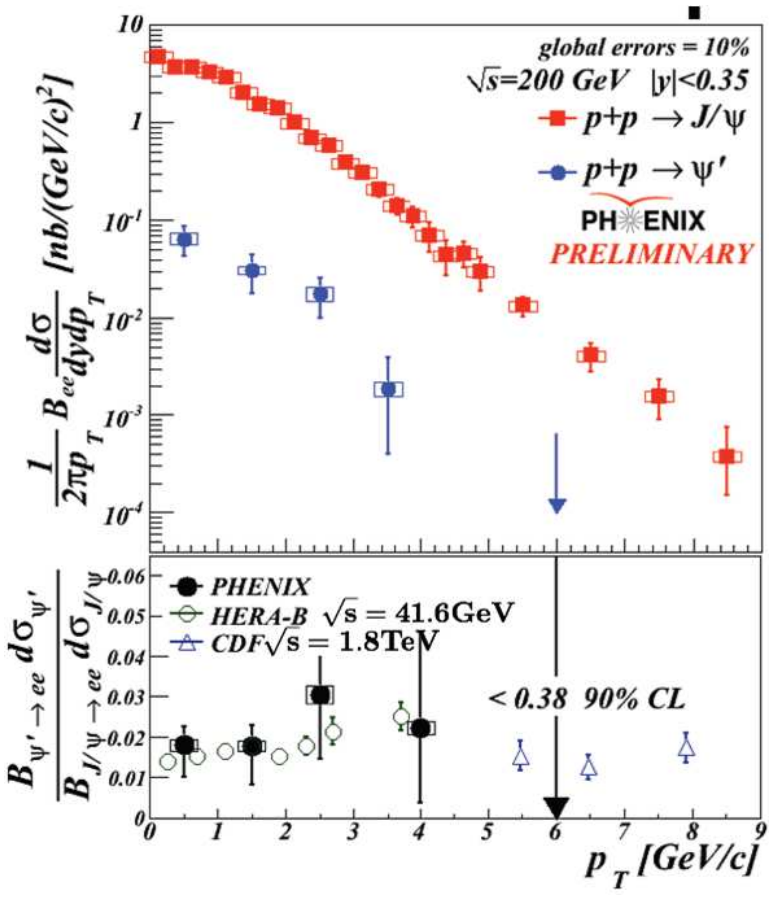

Figure 2: J/ψ and ψ' transverse momentum distributions and their ratio

distribution of the angle, in J/ψ rest frame, between the positive lepton and the axis defined by the J/ψ momentum in colliding hadrons center of mass [16]. This distribution is parameterized by $dN/dcos\theta \propto 1+\lambda cos^2\theta$, where λ is the polarization parameter. In the central rapidity region, the figure 4 displays the values of the λ obtained [16] as a function of the transverse momentum. It is suggesting a trend similar to the one expected by CSM s-channel cut calculations [17]. Extraction in the forward rapidity region in under way, and, as suggested by this model should bring sensitive informations. CSM calculation to next to leading order approximation and inclusion of charm-gluon production [18] lead to a smaller variation with respect to p_T but is still compatible with these data and keeps a difference between central and forward rapidity domains. Might this later feature turn out later to be the ultimate discriminating tool between models since the COM calculation [19] is also consistent with available datas, in the higher p_T part where all calculations are more reliable ?

PHENIX is also performing a program with polarized protons beams. Recently the first measurement [20] of W longitudinal asymmetry has been obtained. These beams also open new perspectives for the quarkonia. The single transverse-spin asymmetry of J/ψ , using measurement in collisions between beams with different polarization, is tentatively explored [21]. This new observable should be sensitive to the production mode: a vanishing asymmetry is predicted [22] in e+p collisions in CSM, and p+p collisions in COM. More data in p+p and also e+p is needed. In it final remarks D. Kharzeev [23] underlined the interest, on top of the separation between color octet and color singlet mechanisms with unpolarized beams, of measuring the quarkonia angular distribution of the spin asymmetry [24] with polarized beams to get access to the gluon helicity distribution in the proton.

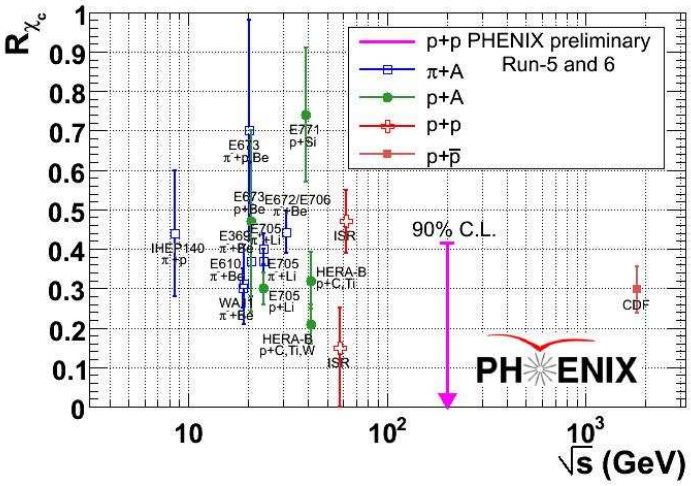

Figure 3: J/ψ feed -down fraction from χ_c in various experiment as a function of the collision energy

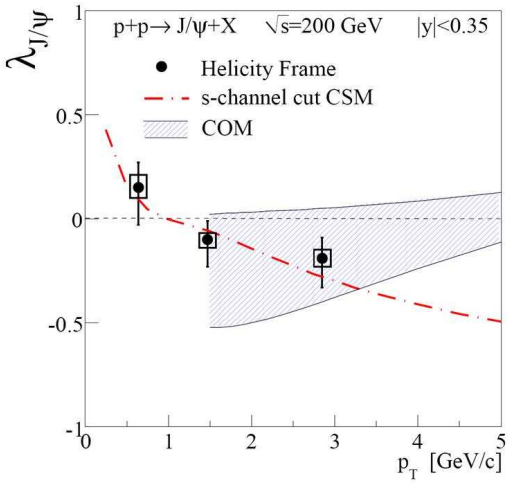

Figure 4: J/ψ polarization as a function of the transverse momentum, compared to theoretical predictions (see text)

References

1. F. Abe et al. *Phys. Rev. Lett.* **79**, 578 (1997).
2. A. Abulencia et al. *Phys. Rev. Lett.* **99**, 132001 (2007).
3. H.Pereira Da Costa, [PHENIX Collaboration], Proceedings in this volume.
4. A. Adare et al. [PHENIX Collaboration],*Phys. Rev. Lett.* **98**, 232002 (2007)
5. R.Vogt, private communication, see *Phys. Rev.* C **81**, 044903 (2010)
6. S.J. Brodsky and J.P. Lansberg *Phys. Rev.* D **81**, 051502(R) (2010)
7. F. Karsch, D. Kharzeev and H. Satz *Phys. Lett.* B **637**, 75 (2006)
8. Calculated from F.Abe et al. *Phys. Rev. Lett.* **79**, 572 (1997)
9. I. Abt et al. *Eur. Phys. J* C **49**, 545 (2007)
10. P. Faccioli, C. Lourenço, J. Seixas and H.K. Wöhri, JHEP **10**, 004 (2008)
11. C.L. da Silva for the PHENIX Collaboration, *Nucl. Phys.* A **830**, 227c-230c (2009)
12. F. Cooper, M. X. Liu, G. C. Nayak, *Phys. Rev. Lett.* **93**, 171801 (2004)
13. H.Haberzettl and J.P. Lansberg, *Phys. Rev. Lett.* **100**, 032006 (2008)
14. J.P. Lansberg, these proceedings, and reference [6]
15. V.A. Khoze, A.D. Martin, M.G. Ryskin, W.J. Stirling, *Eur. Phys. J* C **39**, 163 (2005)
16. A.Adare et al. Transverse momentum dependence of J/ψ polarization at midrapidity in $p+p$ collisions at $\sqrt{s} = 200$ GeV, arXiv:0912.2082, to be published in Physical Review D
17. J.P. Lansberg and H.Haberzettl ,archiv 0806.4901.v1, *AIP Conf. Proc.* **1038**, 83 (2008)
18. J.P. Lansberg, arXiv1003.4319v1, 23 march 2010
19. H. S. Chung, S. Kim, J. Lee, and C. Yu, *Phys. Rev.* D **81**, 014020 (2010)
20. K. Okada , [PHENIX Collaboration], arXiv1006.1106v1
21. C.Aidala, Single-Spin-Asymmetries and Transverse-Momentum-Dependent Distributions at RHIC, Electromagnetic Interactions with Nucleons and Nuclei, Milos Island, Greece, September 27-October 2, 2009
22. F. Yuan *Phys. Rev.* D **78**, 014024 (2008)
23. D.Kharzeev, these proceedings
24. R.L. Jaffe and D. Kharzeev *Phys. Lett.* B **455**, 306 (1999)